Sensitivity-enhanced NURBS-based optimisation of the TU Berlin Stator with geometric constraints

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ABSTRACT

Adjoint CFD has been proven to be an efficient method in aerodynamic shape optimisation able to provide flow sensitivities for a large number of design parameters at very low computational cost, hence has become a standard tool in industrial workflows. Another trend in industry is to include the CAD description of the geometry into the optimisation loop, which allows to produce the optimal shape directly in a CAD format. To do this, one could optimise the parameters of a CAD model's construction algorithm. Alternatively, it is possible to work with the boundary representation (BRep) as stored e.g. in the STEP file format. In particular, the shape can be controlled by modifying control points of Non-rational B-Splines (NURBS). Whether a parametric CAD or the BRep is used, gradient-based optimisation requires to compute CAD sensitivities - derivatives of mesh point coordinates on CAD surfaces with respect to the design parameters. Another concern is to ensure space is rich enough to capture the relevant flow features.

In this paper we use the automatically differentiated (AD) version of the open-source CAD-kernel Open Cascade Technology (OCCT) [1]. The advantage of applying AD to the entire kernel of OCCT is that a) derivatives for all of OCCTs algorithms are available and b) the derivatives are exact and not affected by truncation or round-off errors as finite-differences would be.

Parametrisation is achieved through the NSPCC approach which considers all NURBS control points to be moveable, subject to geometric constraints such as e.g. geometric continuity across arbitrary patch interfaces, or thickness and radius constraints [2]. In this work we further extend NSPCC by coupling the flow and adjoint solvers with an adaptive parametrisation. New control points are added in regions where sensitivities projected on the CFD surface mesh cannot be eliminated. OCCT's knot insertion tools are then used to locally enrich the BRep and hence the design space.

Convergence of flow, adjoint and design variables is achieved by using a block-coupled simultaneous time-stepping or 'one-shot' method. For each design step the flow solver is converged to a residual threshold which is a function of the gradient magnitude: while using only approximately converged, inexpensive solutions in the early design phases far from the optimum, the convergence requirements are tightened as the optimum is approached and gradient magnitude decreases. Finally, the design is updated using steepest-descent or quasi-Newton algorithms controlled by Armijo line searches.

The paper will present results on a generic S-Bend climate duct and on the TU-Berlin stator.

REFERENCES

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